# Mode Transition Modeling and Control

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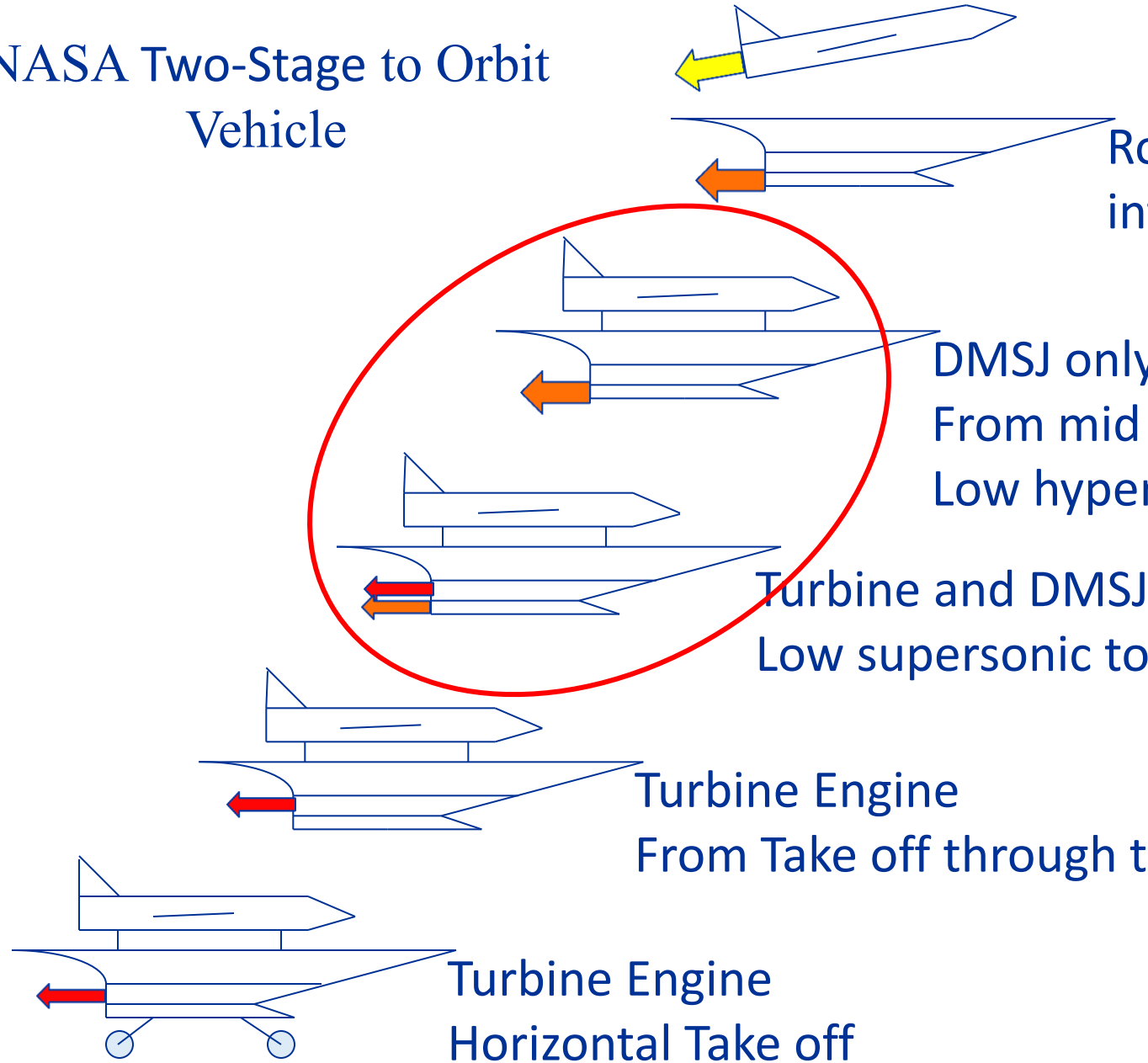
**NASA Glenn Research Center**
**Cleveland, Ohio**


**5th Propulsion Control and Diagnostics (PCD) Workshop**
**Cleveland OH, September 16, 2015**

# NASA Two-Stage to Orbit Vehicle



Rocket insert into space

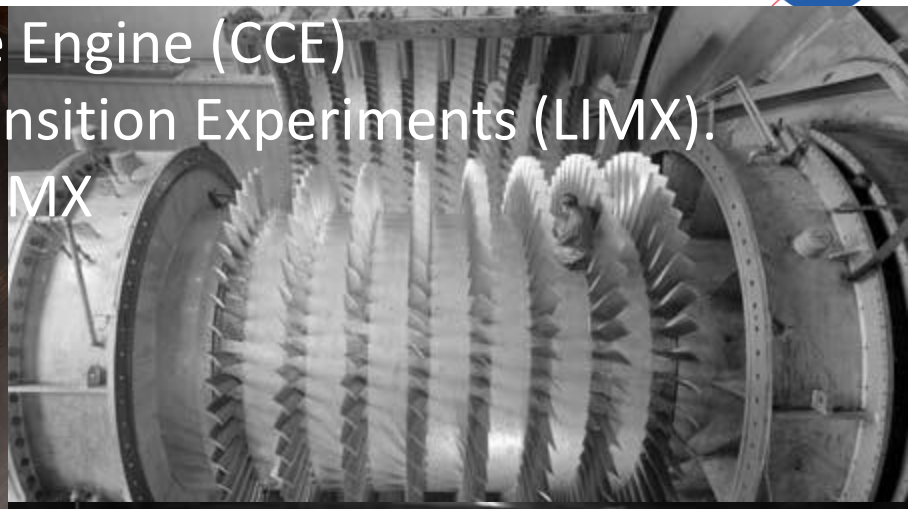
DMSJ only
From mid supersonic to Low hypersonic

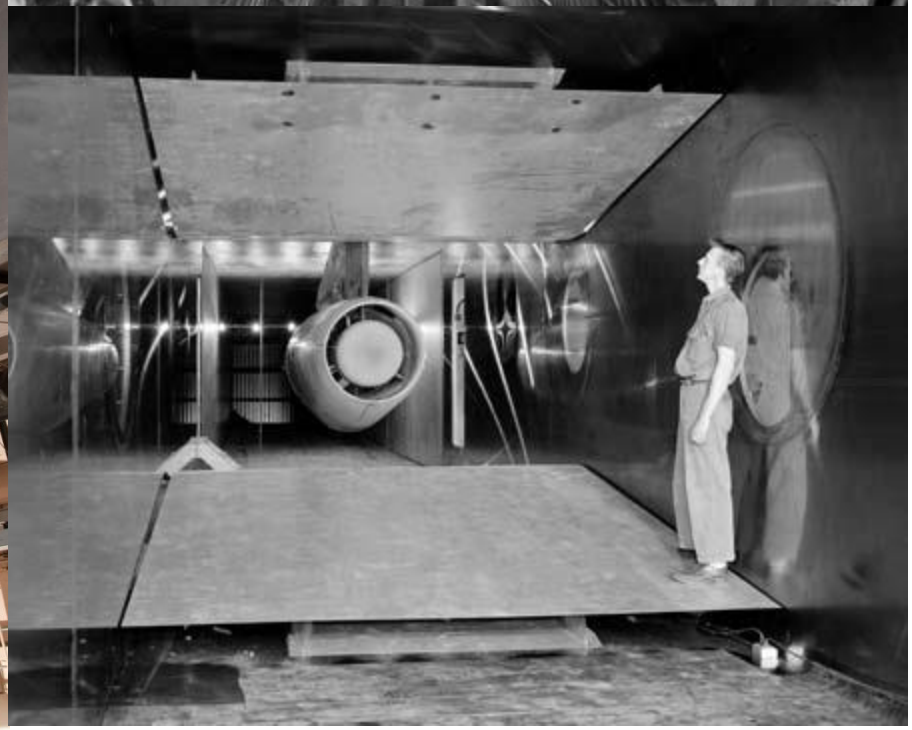
Turbine and DMSJ
Low supersonic to mid supersonic.

Turbine Engine
From Take off through transonic.

Turbine Engine
Horizontal Take off

# Combined Cycle Engine (CCE) Large-Scale Inlet for Mode Transition Experiments (LIMX). CCE-LIMX



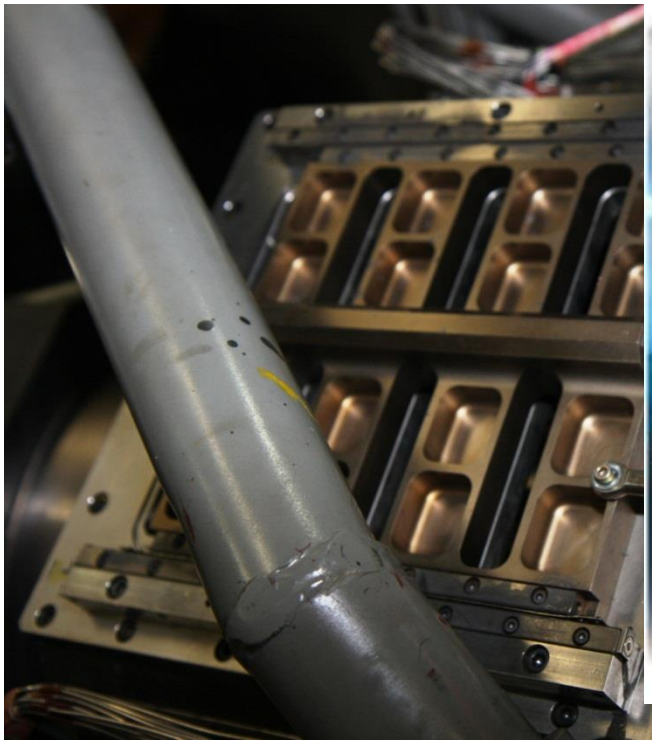


# Team

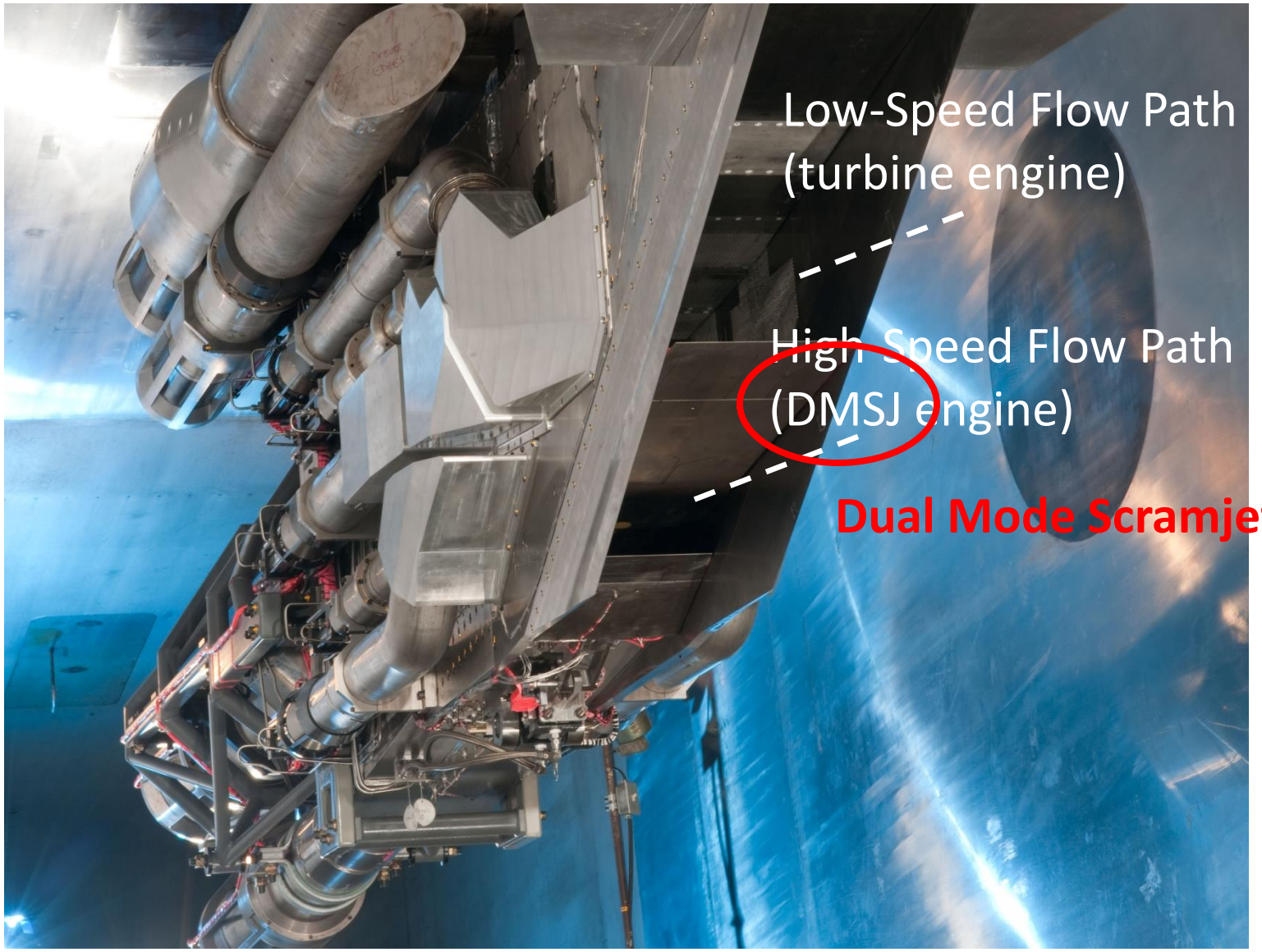
- NASA GRC Research and Engineering Directorate (L):
  - Communication and Intelligent Systems Division (LC)
    - Intelligent Control and Autonomy Branch (LCC)
      - Jeffrey T. Csank, Thomas J. Stueber, Randy Thomas, Daniel R. Vrnak
  - Propulsion Division (LT)
    - Inlets & Nozzles Branch (LTN)
      - Paul A. Bartolotta, David Davis, Lancert E. Foster, Dave Saunders
  - Materials and Structures Division (LM)
    - Mechanisms and Tribology Branch(LMT)
      - Amanda Stevenson
- NASA GRC Facilities Directorate:
  - Facilities Testing Division (FT),
    - Wind Tunnel and Propulsion Test Branch (FTD).
- NASA GRC Space Flight Systems Directorate (M)
  - Exploration Systems Project Office (MX)
    - Steven A. Sinacore
- AFRL Wright Patterson Air force Base
  - Greg Bruening (RQTE)
  - Jeffrey Donbar (RQHF)
  - Alex Maag (RQHP)
  - Heidi Wilkin (RQHP)
- Industry Partners
  - TechLand Research Inc.
    - Bobby W. Sanders,
    - Lois J. Weir
  - Williams International.

# Outline

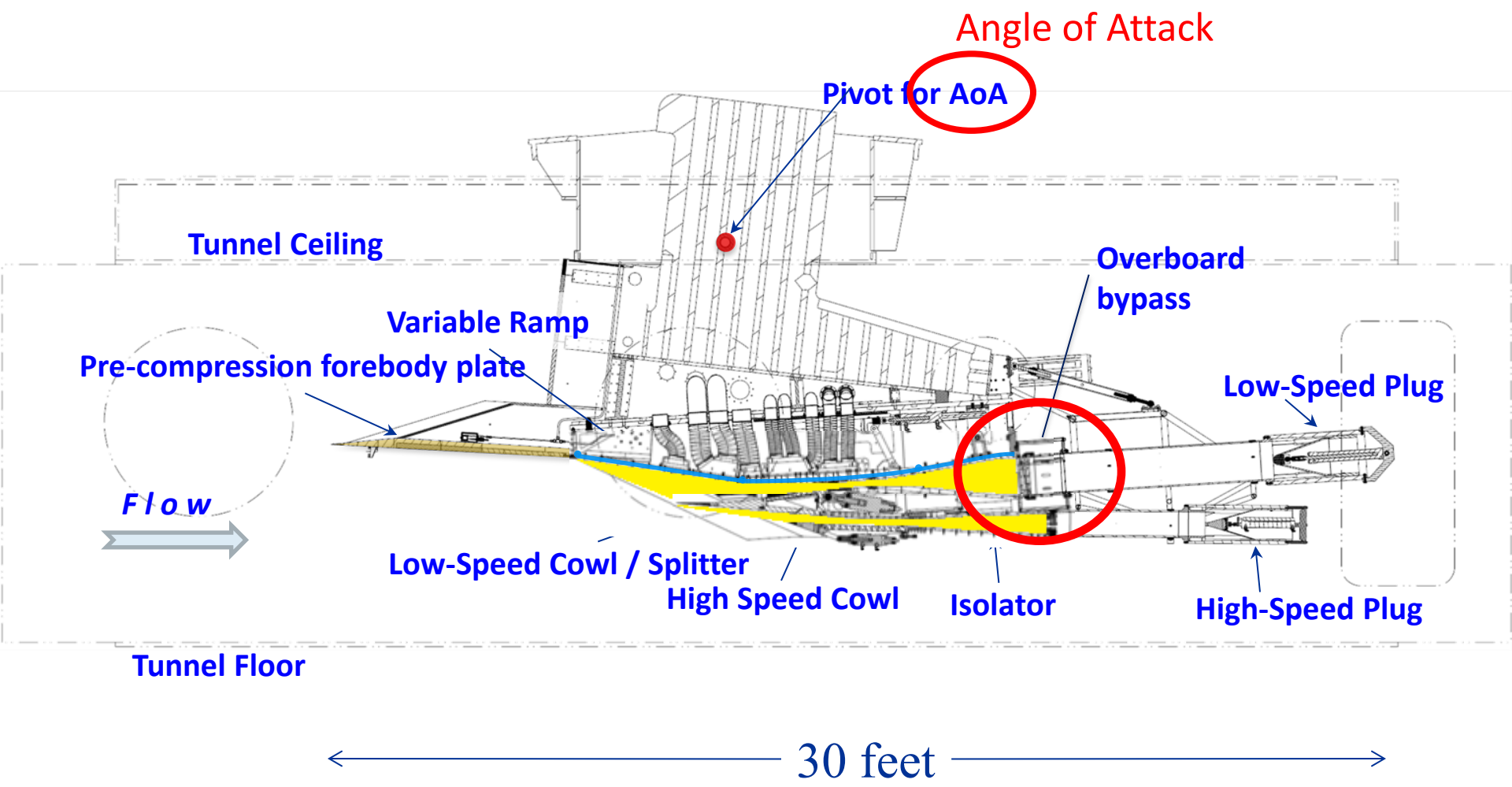
- Overview of CCE-LIMX Inlet System
- Control Effecters
- Control Design
- Test Plans
- Summary



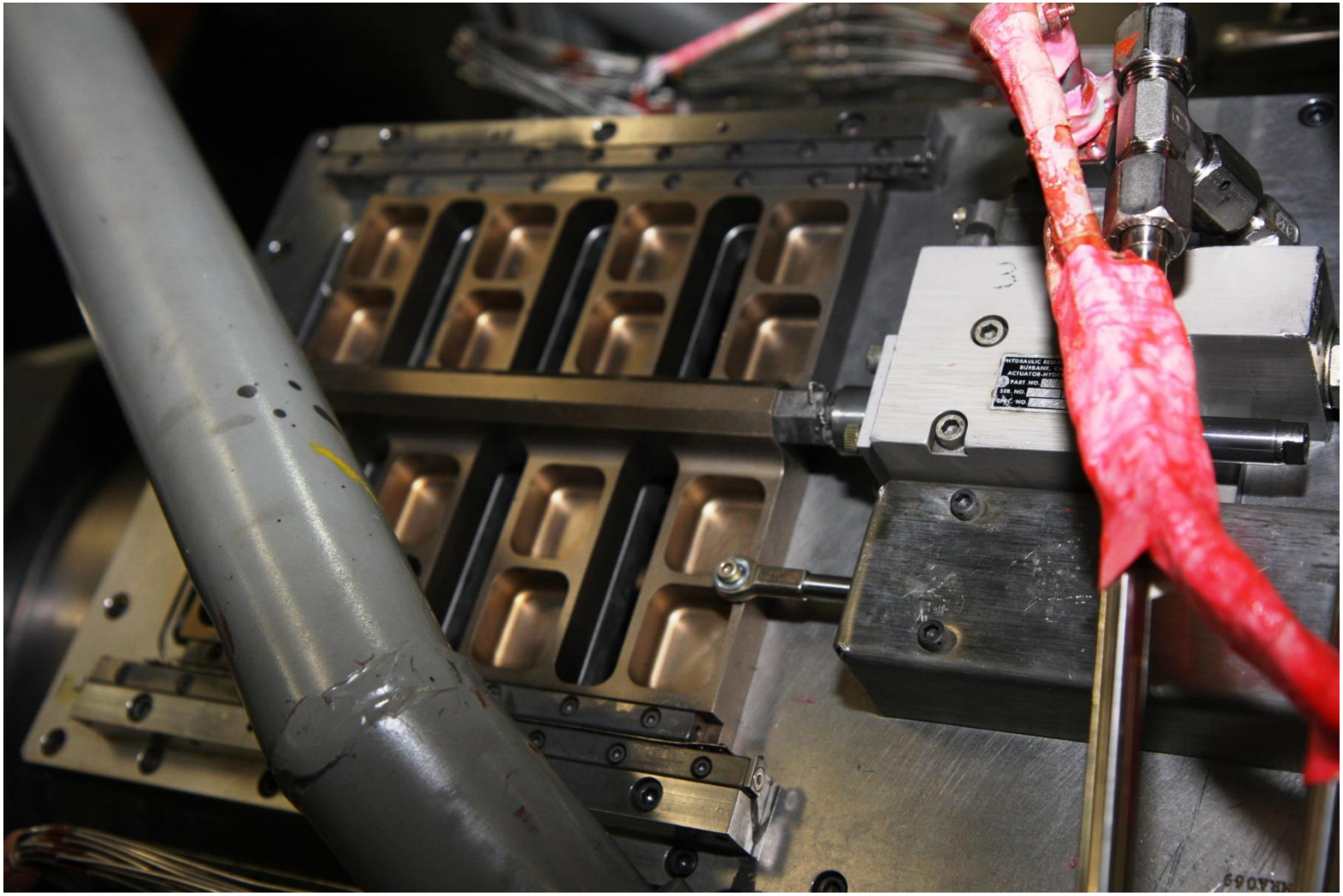
# CCE-LIMX Model



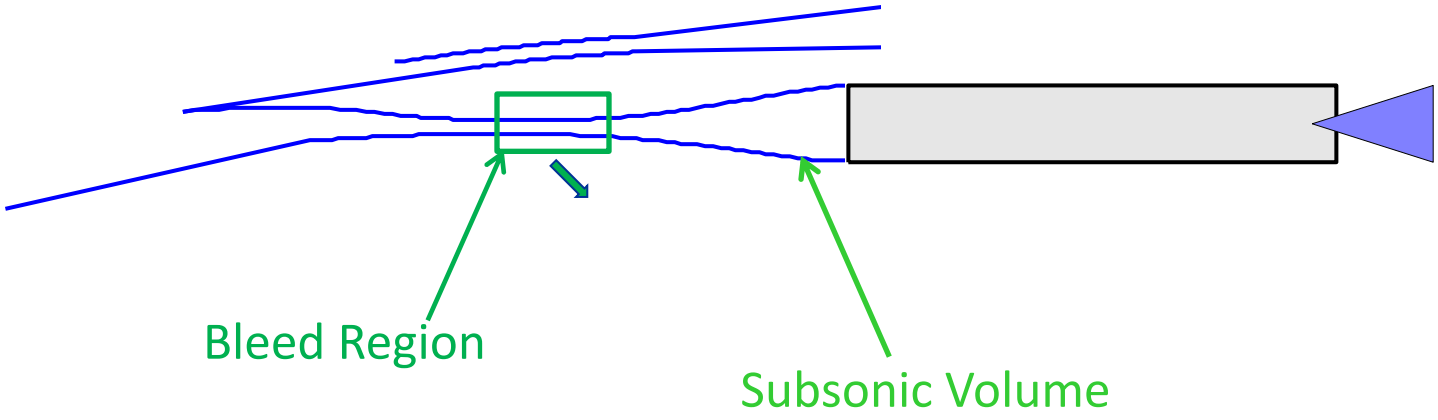
# CCE-LIMX Model Features



# Control Effecters



# Phase 1: Inlet Characterization and Performance Testing



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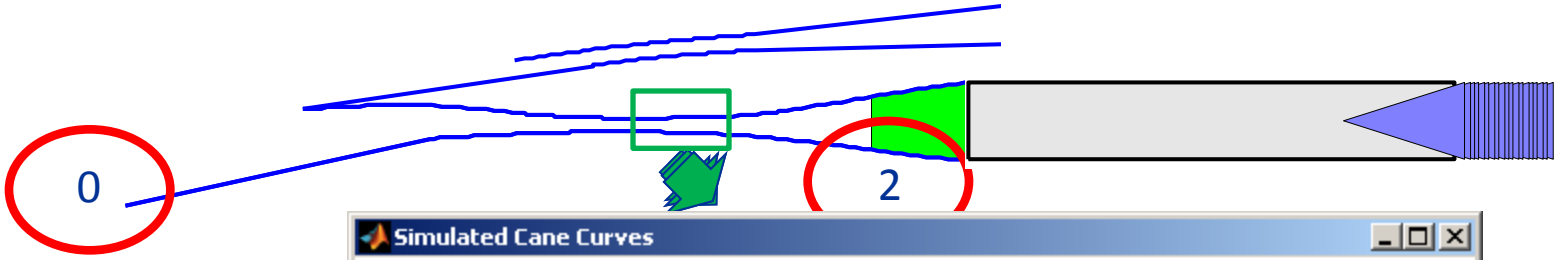


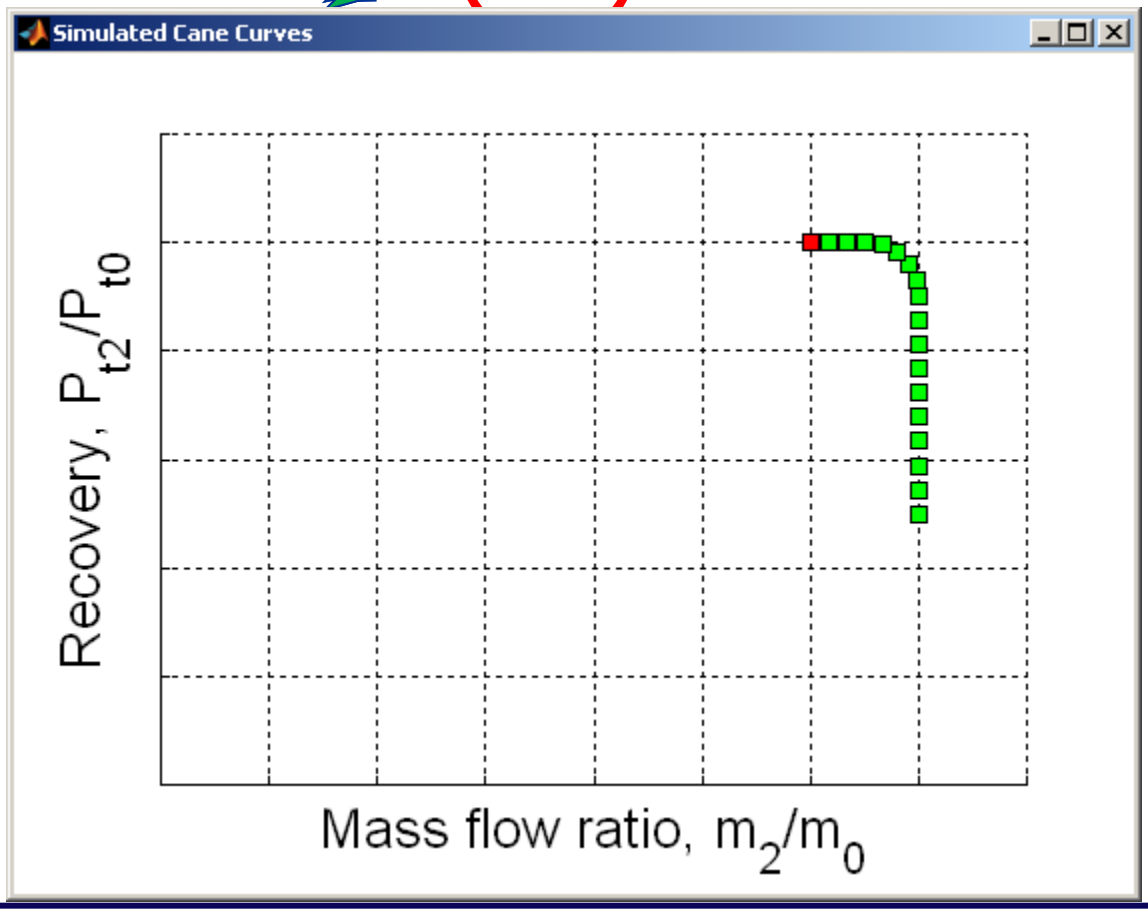

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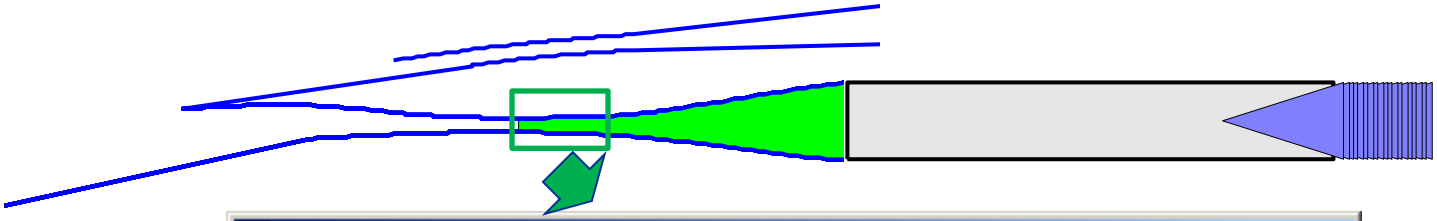

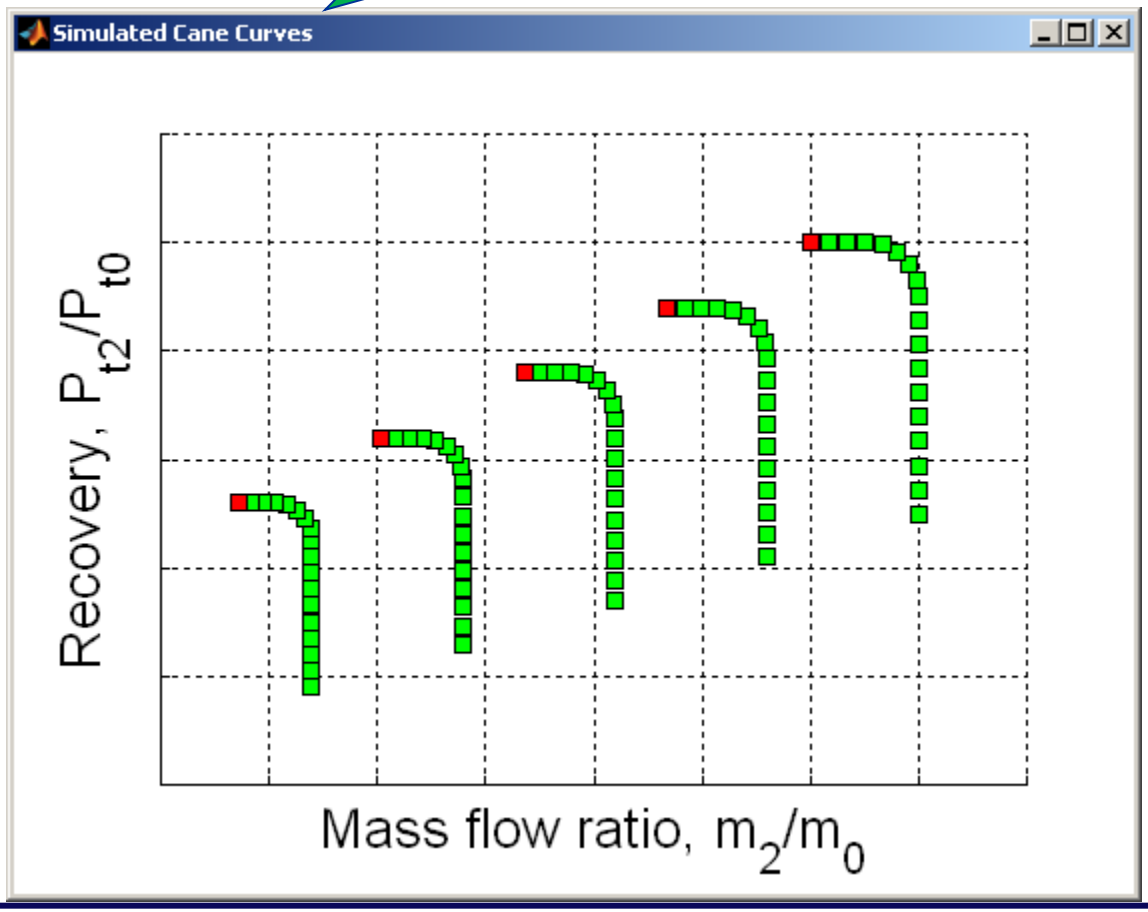

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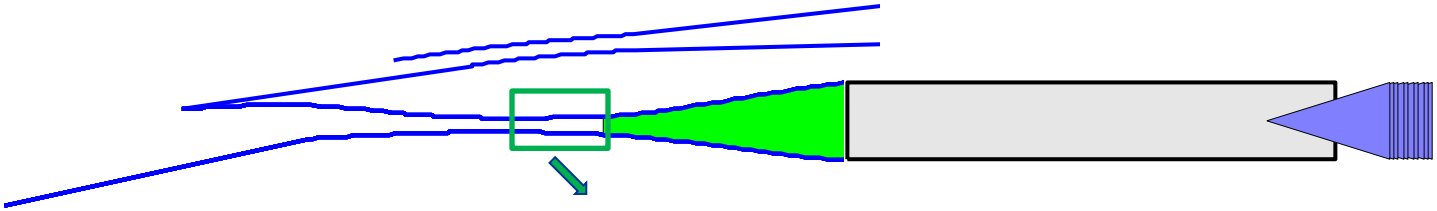
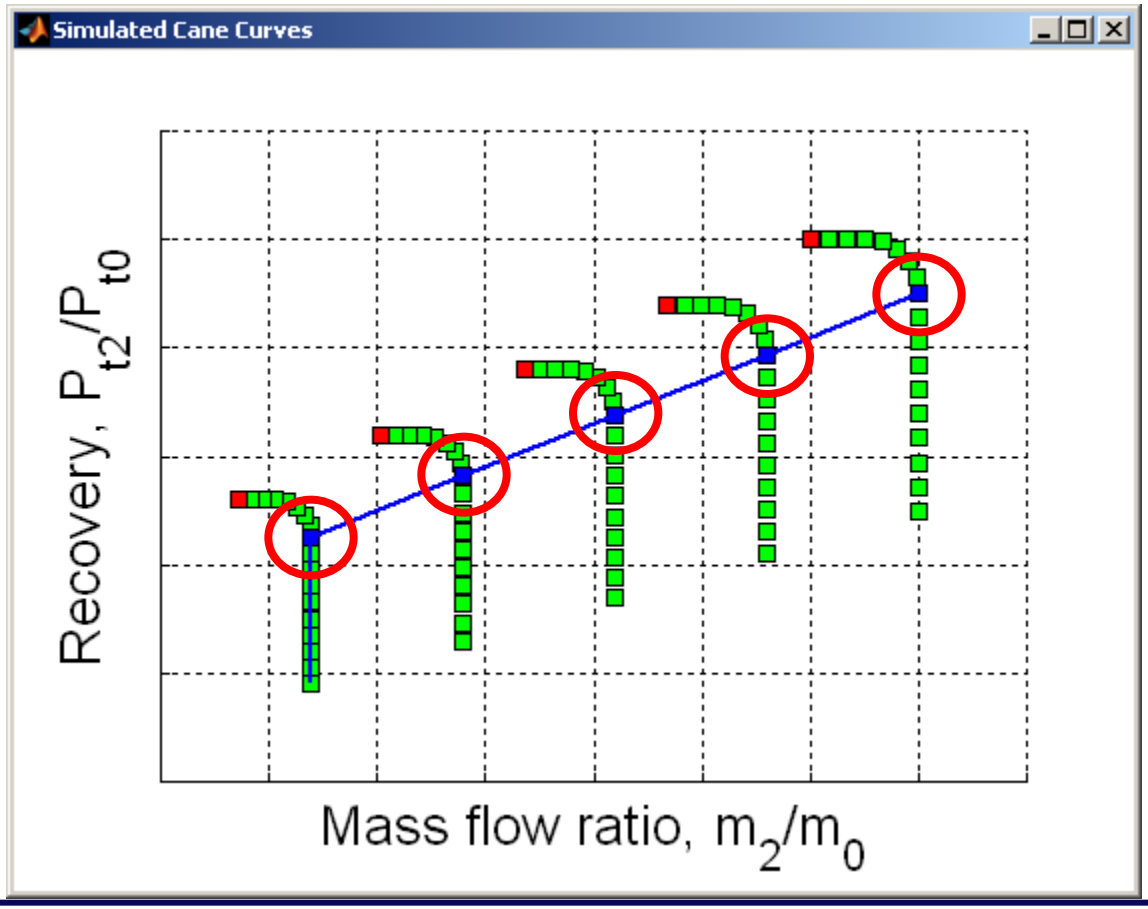
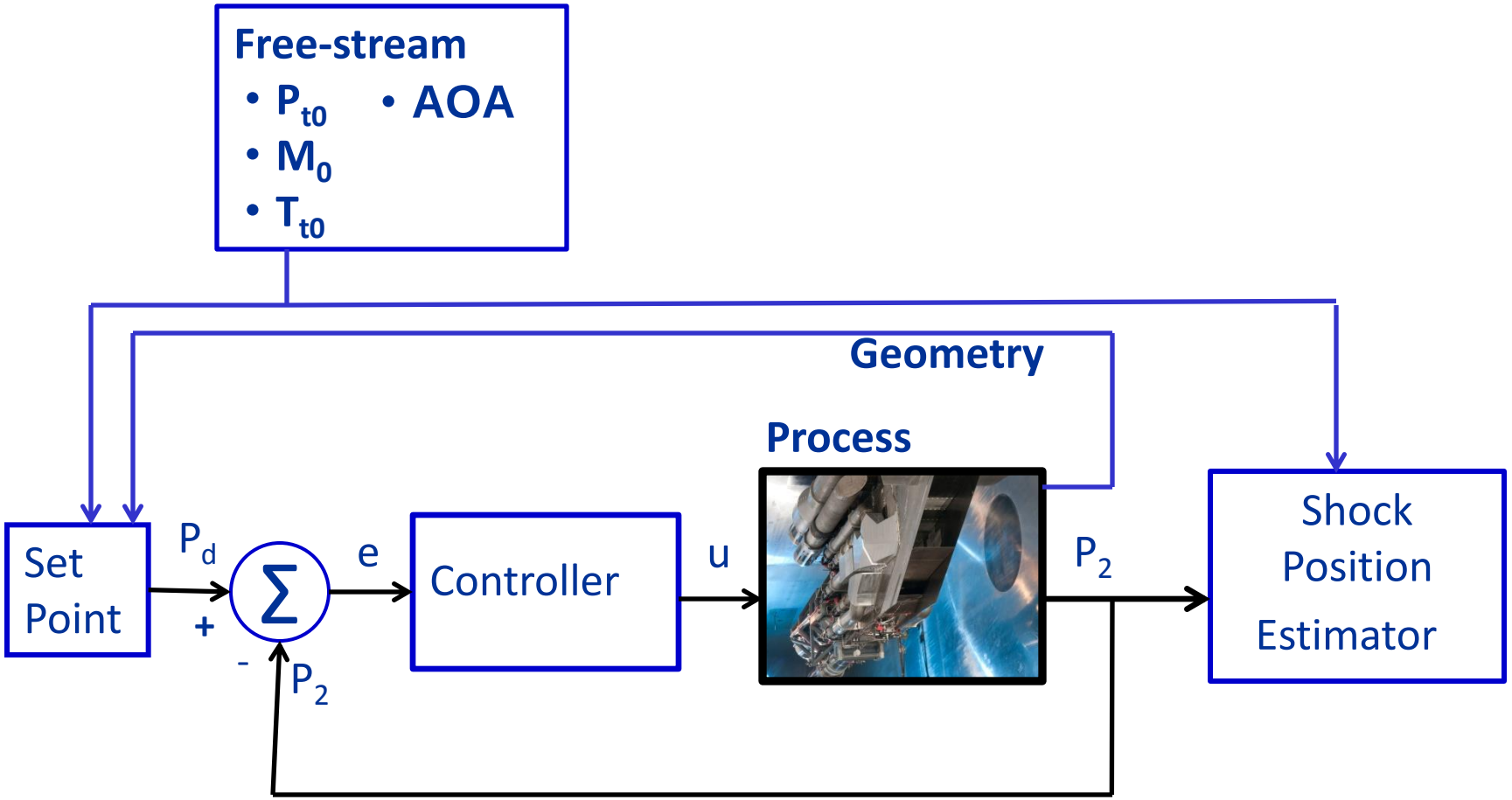




# Control Design



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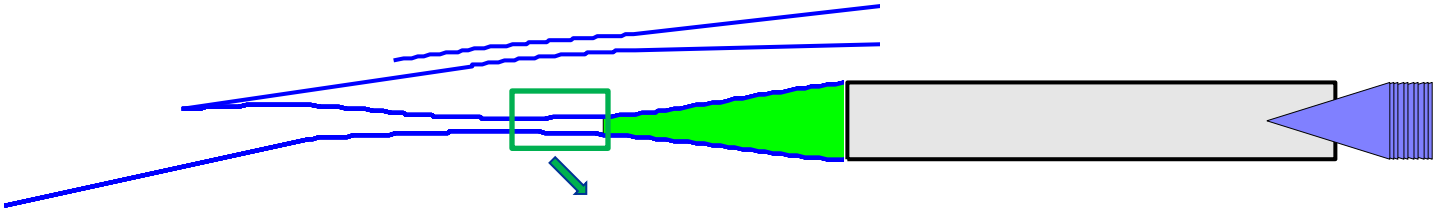
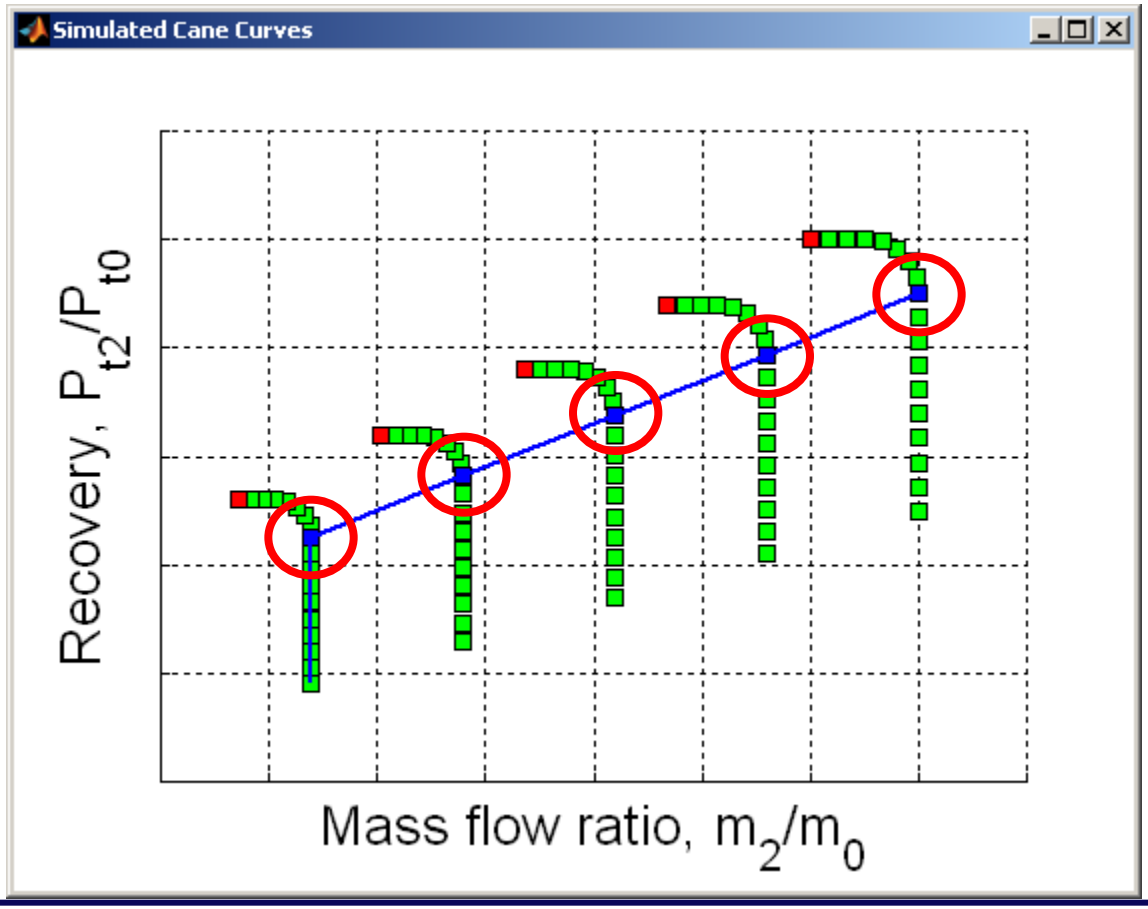
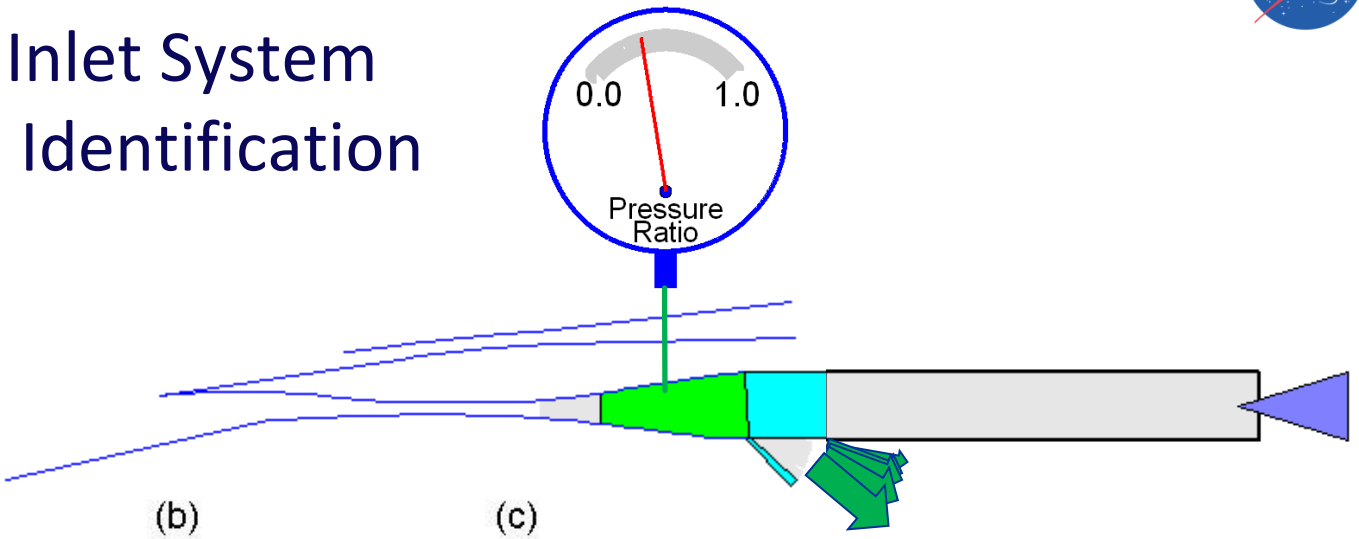
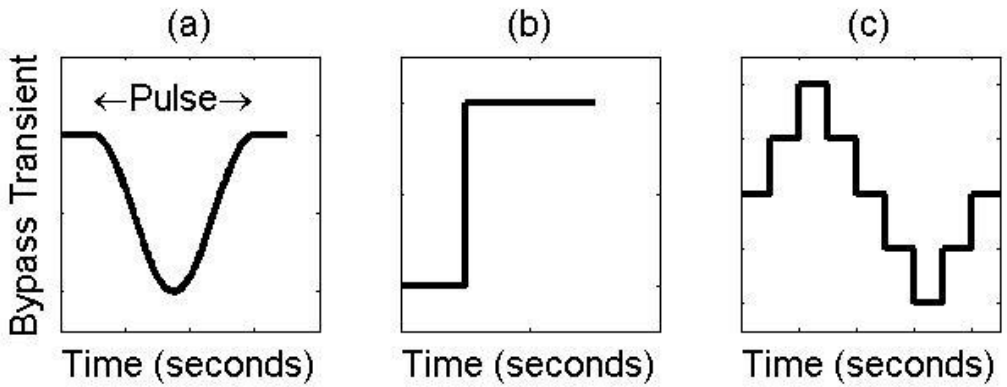
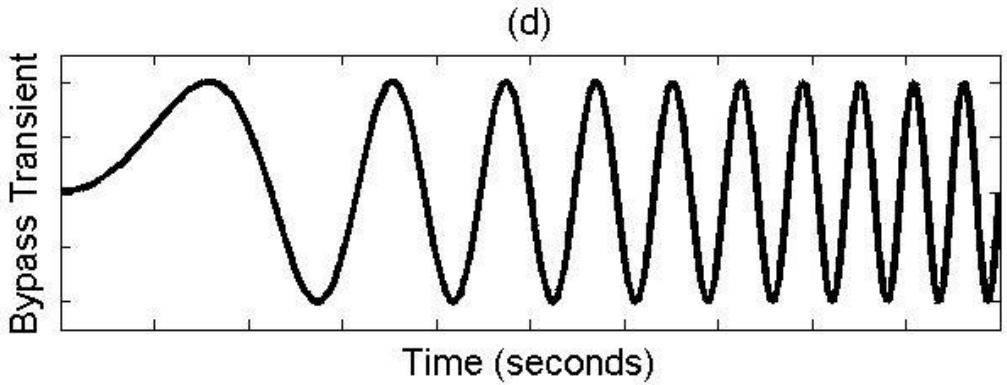




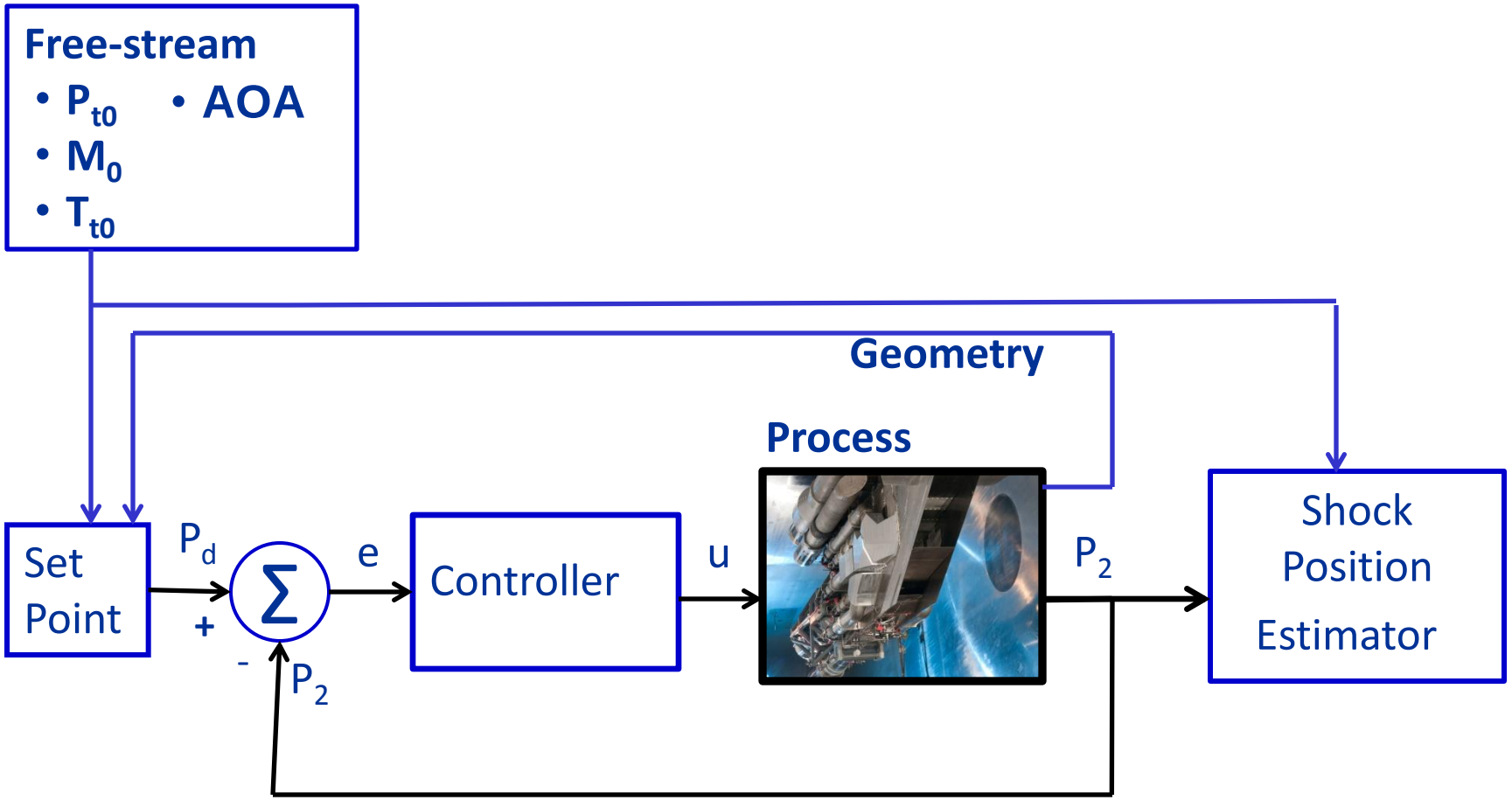
# Phase 2: Inlet System Identification



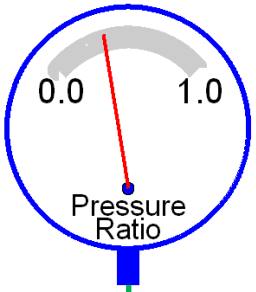



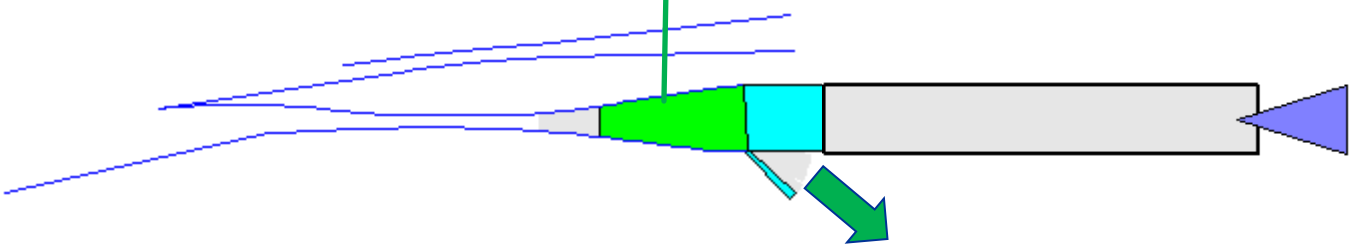
# Phase 3a Control Experiments

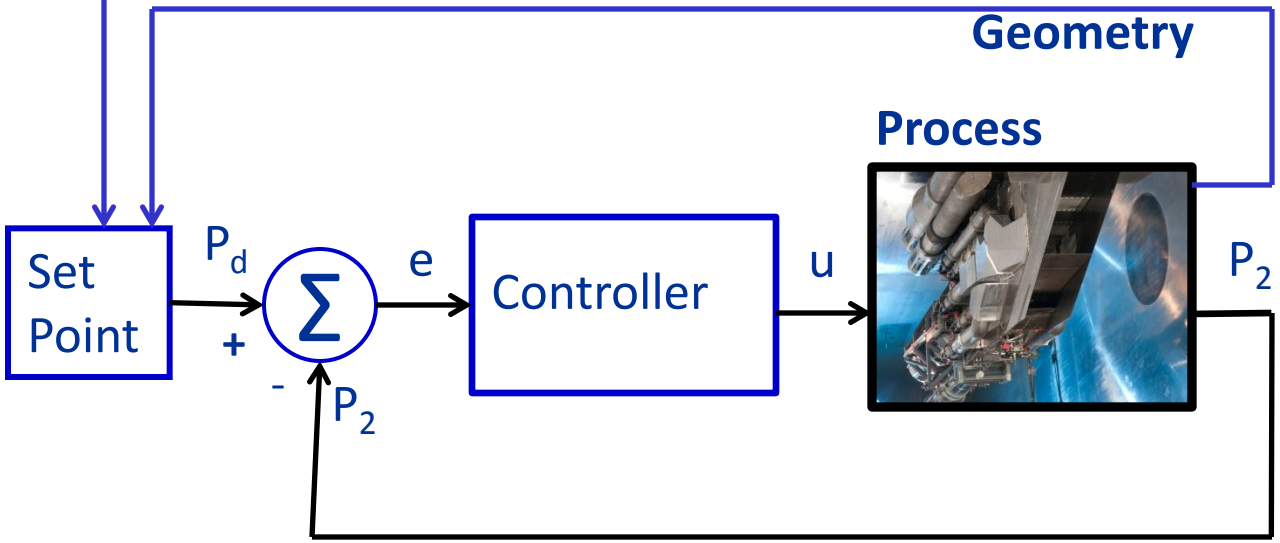


# Phase 3a Control Experiments




**Free-stream**
- $P_{t0}$
- AOA
- $M_0$
- $T_{t0}$





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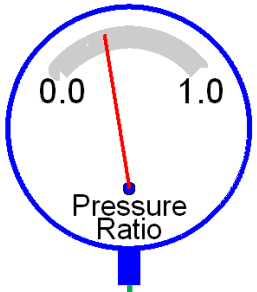


**Free-stream**
- $P_{t0}$
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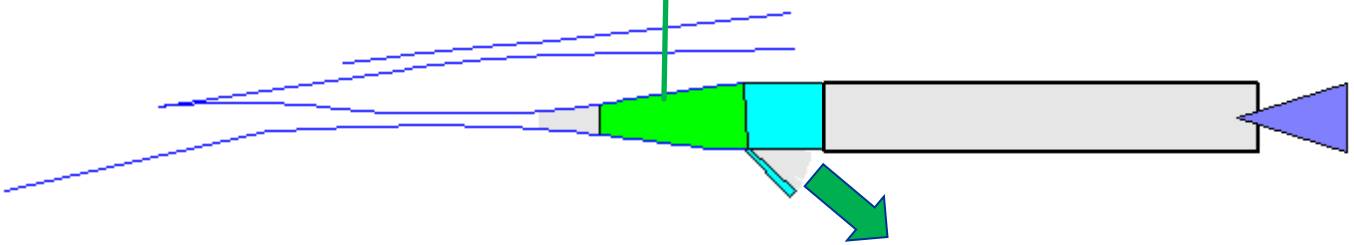

**Geometry**

**Process**

Set Point

$P_d$

$\Sigma$

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$P_2$

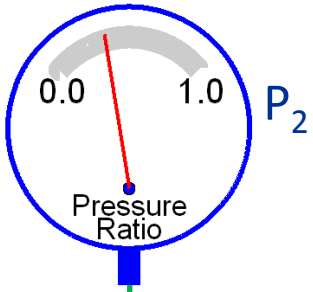
e

Controller

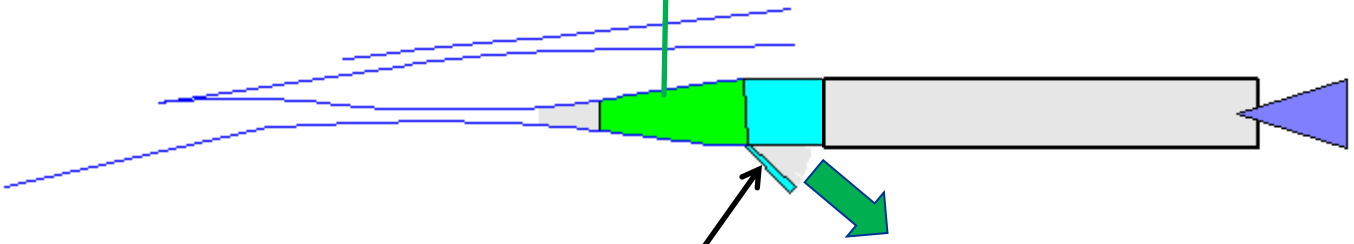
u

$P_2$

# Phase 3a Control Experiments




**Free-stream**
- $P_{t0}$
- AOA
- $M_0$
- $T_{t0}$



**Geometry**

**Process**

Set Point

$P_d$

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$P_2$

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Controller

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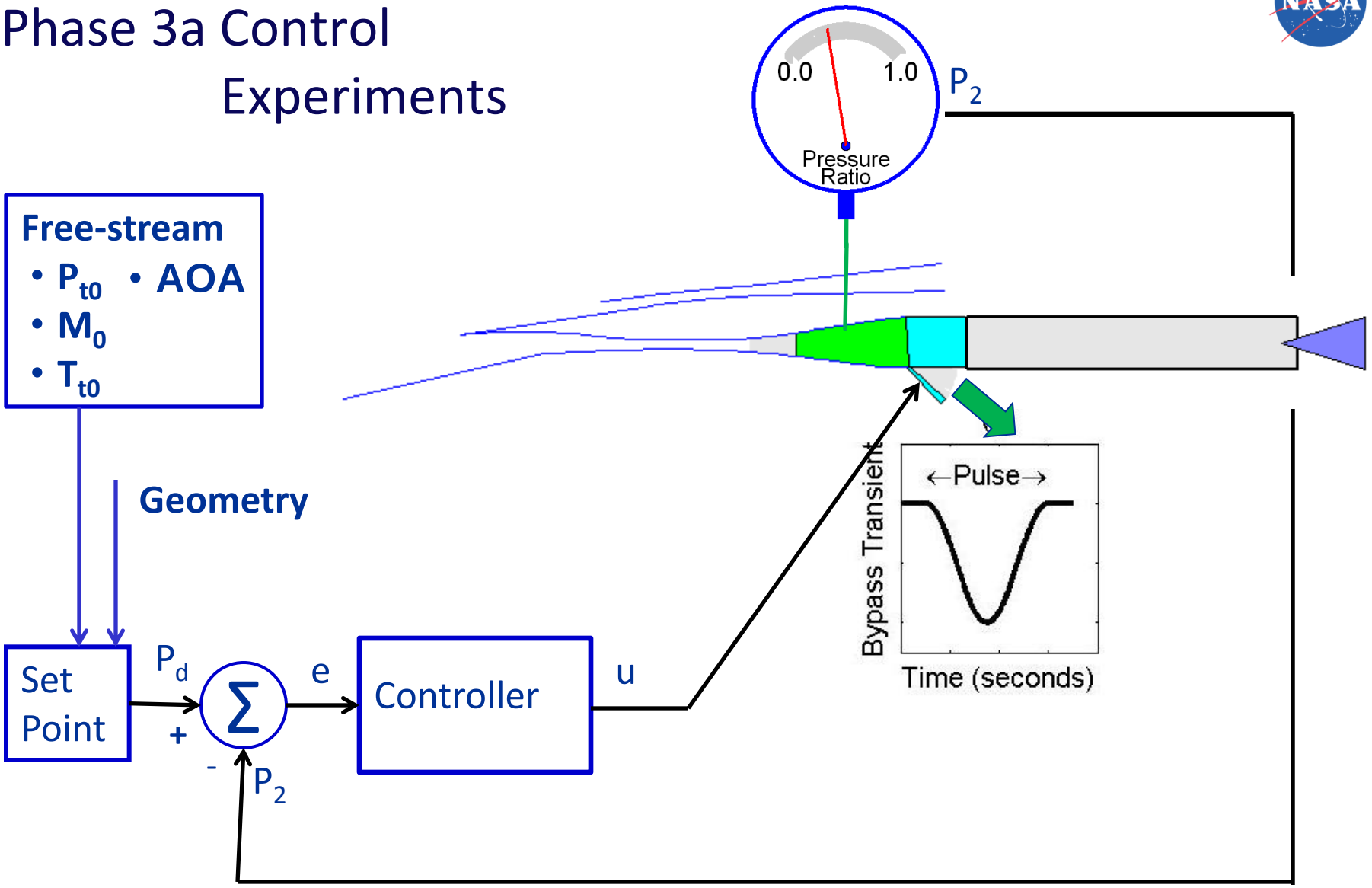
$P_2$

# Phase 3a Control Experiments



# Beyond Phase-3a

- Phases 3b and 3c will be experiments designed to test readiness for installation of a turbine engine at the aft end of the subsonic diffuser.
- Phase 4 is planned to be mode transition tests using a turbine engine instead of the low-speed flow-path cold pipe and mass flow plug assembly.

# Summary

- Combined Cycle Engine (CCE) Large Scale Inlet for Mode Transition Experiments (LIMX)
  - Designed,
  - Built,
  - Installed in NASA GRC 10- x 10-foot SWT
  - Completed Phase-1, Phase-2, and Phase-3a testing
  - Preparing for Phase-3b and Phase-3c testing.

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- Saunders, J.D., Slater, J.W., Dippold, V., Lee, J., Sanders, B.W., and Weir, L.J., "**Inlet Mode Transition Screening Test for a Turbine-Based Combined-Cycle Propulsion System**," JANNAF, Boston MA, May 2008.


# Questions?